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Contribution of Cool Dust to the FIR Brightness Distribution of NGC 6946 Sc(s)II

G. Engargiola and D.A. Harper
University of Chicago, Yerkes Observatory
Williams Bay, WI

I. Introduction

A few galaxies have been observed at submillimeter wavelengths (Stark et al., 1988; Eales, Wynn-Williams, and Duncan, 1988). These observations do not support the hypothesis that there exist substantial amounts of cool dust generating submillimter radiation in excess of predictions from modified blackbody curves of the form $(1/\lambda)^{1.5}B_\nu(\nu,T)$ fit to total 100 and 160μm fluxes. However, we find relatively cold dust(~17-23°K) at several interarm locations in the central 5' x 5' region of NGC 6946 Sc(s)II. Since molecular gas is the predominate constituent of the ISM in this region, such low dust temperatures are indicative of quiescent molecular clouds and low star formation rates. Based on the contribution of cool grains to the 160μm surface brightness distribution, regions of low star formation activity can be identified. A $1/\lambda^{1.5}$ emissivity law is assumed for this analysis.

II. Far Infrared Emission from NGC 6946

The central 5' x 5' region of NGC 6946 has been mapped at 100 and 160 μm with the 32 channel U.Chicago FIR Camera on the KAO. The beamsize was 45". The far infrared brightness distributions are shown in **Fig. 1**. The peak brightnesses of the 100 and 160μm maps are 65 Jy/beam and 59 Jy/beam, respectively. The contour spacings are 2 Jy/beam. A nuclear excess and a bisymmetric spiral pattern superimposed on an exponential disk are apparent at both wavelengths. The hydrogen alpha (Bonnerel and Boulsteix), radio continuum (van der Kruit, Allen, and Rots), integrated CO J=1->0 (Young and Scoville; Tacconi and Young), and far-infrared distributions of NGC 6946 (Engargiola, Harper, and Jaffe) have average radial profiles which peak strongly at r=0. The 100μm flux follows the resolved hydrogen alpha distribution more closely than the 160μm flux, which more faithfully traces the I-band intensity distribution (Tacconi and Young). About 75% of the far-infrared luminosity of NGC 6946 originates from the central 5' of the disk.

III. Two Temperature Decomposition of 160 μm Flux

The far infrared brightness distribution can be represented at each position by a sum of two modified blackbody components, $f\nu[T(1),T(2)] = a(1)\nu^{1.5}B\nu[T(1)] + a(2)\nu^{1.5}B\nu[T(2)]$ [Jys/beam], where T(1,2) = 20,35°K, $\tau\nu(1,2) = a(1,2)\nu^{1.5}$. One solves for two optical depths, the 'a' coefficients, using both the 100 and 160μm maps. The pair of temperatures were empirically chosen to maximize the contribution of the lower temperature component, subject to the constraint that the components $a(i)\nu^{1.5}B\nu[T(i)]$ be greater than zero over the entire map and that the ratio of the integrated fluxes $F\nu(350\mu m)/F\nu(160\mu m) \approx 5.0\pm1.0$, so as to be consistent with integrated far infrared and submillimeter measurements of other spiral galaxies e.g. NGC 4254, NGC 4501, NGC 4654 (Stark

et al.), and NGC 4736 (Jaffe, Engargiola, and Harper). Increasing the difference $\Delta T = T(2)-T(1)$ increases the cold component but results in a warm component which is less than zero over portions of the map if $\Delta T > 16°K$. The decomposition will filter the brightness distribution into parts where the effects of warm and cool dust are enhanced. The results of this decomposition are shown in **Fig 2.** The warm and cold dust component contours are superimposed on a grey scale representation of the hydrogen alpha - smoothed to 45" resolution - and are labelled **Fig. 2a.** and **2b.**, respectively; the contour spacing is 2Jy/beam.

The average surface brightness of the cold dust 160μm component is 1.5 Jys/(')^2. The ratio of this to the average total 160μm surface brightness is $[f\nu(160)]_{20°K}/f\nu(160)= 0.14$. The total flux from the 20°K dust component from the central 5'.0 x 5.'0 region of the galaxy is 39 Jys. This component peaks at 14 Jys/(')^2 about 0.'5 east of the galaxy center; other peaks of 6 Jys/(')^2 occur in interarm regions to the E and NW at r > 6 kpc. Extrapolating the 20 and 35°K flux components with the model from 160 to 350μm yields an average surface brightness of 2.1 Jys/(')^2, hence the ratio of the total 160 to 350μm flux is 5.3 and the decomposition yields a spectrum consistent with blue Virgo Cluster spirals. The total 160μm flux from cool dust is estimated to be 45 Jys; extrapolating to 100μm gives 25 Jys or 7% of the total 100μm flux of 344 Jys measured by IRAS (Rice et al). Hence, this emission model predicts a small contribution by 20°K grains to the total 100μm luminosity fv(100).

a) Spatial Relation of Cool Dust Emission to Regions of Massive Star Formation

The number surface density of HII regions - with luminosities > ~10^{38} ergs/s - for the central 5'.0x5.'0 of the galaxy is 8/(')^2. This surface density has a range 3-10/(')^2 for the inner disk and interarm regions and 10-20/(')^2 for the spiral arms; the highest surface density of HII regions, 40/(')^2, occurs at the center of the galaxy. The strongest peaks in the cold dust distribution occur where the number surface density is 6-7/(')^2, slightly below average. Also, the HII regions are on average 3-10 more luminous in hydrogen alpha for positions along the spiral arms than for positions where the 20°K dust component is detected at 160μm. It can be seen that (1) the 20°K dust component contributes over half the infrared luminosity from certain regions of NGC 6946 and (2) the relative size of the cold dust contribution is related to the amount of ionizing radiation, to the extent that hydrogen alpha is a measure of the ionizing UV continuum i.e. where there are fewer massive stars powering the ISM, there is more 20°K dust, not too surprising.

The average radial profiles of the 20°K and 35°K 160μm components appear in **Fig. 3a**. The 35°K component drops steeply with radius from the center of the galaxy but levels off beyond radius 1.'5, where increasing numbers of HII regions resolved in hydrogen alpha light are found. The 20°K component peaks between the galaxy center and radius 1.'0, dips to a minimum at radius 2.'2 and begins to increase past 2.'5. Cool dust appears to contribute a higher fraction of the total 160μm surface brightness at large radii. The radial profiles are uncorrected for the inclination of the galaxy.

b) Expected Cool Dust Contribution to 350 μm Flux

Fig. 3b is the average radial submillimeter brightness profile of NGC 6946 obtained by extrapolating the 20°K and 35°K emission components to

350μm. The submillimeter profile has been normalized to the predicted peak value of 11 Jys/beam. The intervals plotted along with the submillimeter profile represent the span over position angle of the fractional contribution by the 20°k component to the 350μm flux. About 40% of the total 350μm flux is predicted to arise from cold dust. Also clear from Fig. 3b is that cold dust may produce as much as 60% of the submillimeter flux at galactocentric distances greater than 9 kpc.

IV. Recent Observations at 200μm

During a KAO flight series this past May, Engargiola and Harper observed NGC 6946 at 200μm. The data have yet to be calibrated. A preliminary contour map, where the contour levels are linear in raw signal, is shown in **Fig. 4**. Similarity is clear between the 200μm brightness distribution and the 20°K 160μm emission component, possibly indicating a higher relative fraction of the far infrared/submillimeter emission from cool grains in quiescent molecular clouds.

V. Conclusions

We have assumed a two temperature grain model in an effort to decompose the far infrared surface brightness distribution of NGC 6946 into contributions from cool, quiescent and active, star forming regions. This model has some validity; although an oversimplification of the dust energetics, we find from it that, where giant HII regions are sparse, a signifigant fraction of the 160μm emission is emitted by a cool grain component which IRAS could barely detect.

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NGC 6946 Sc(s)II λ100μm

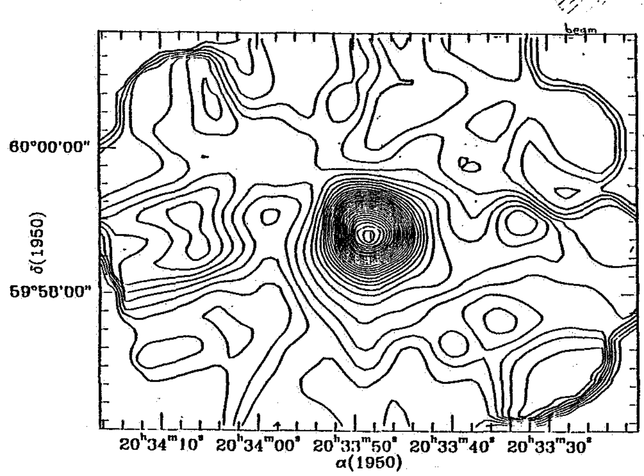

Fig. 1a

NGC 6946 Sc(s)II λ160μm

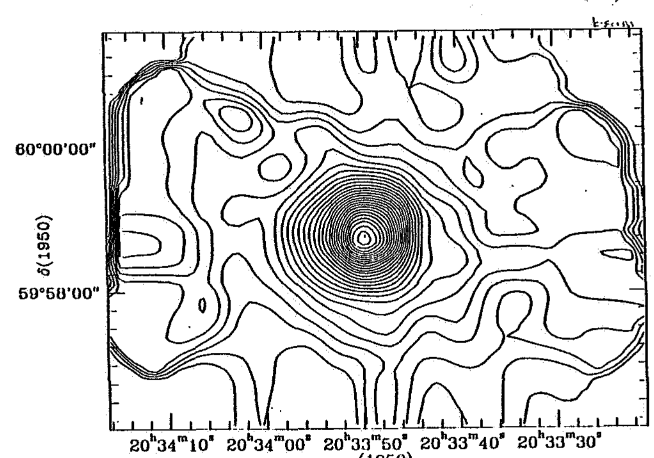

Fig. 1b